

ERUCASTRUM GALLICUM (BRASSICACEAE): INVASION AND SPREAD IN NORTH AMERICA

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ABSTRACT

The invasion and spread of the European *Erucastrum gallicum* (Brassicaceae) in North America are traced from the first collection, in 1903, through 1992. The plant is now known from 29 states of the United States and from all provinces and one territory of Canada. The increasing North American range, shown on four maps, indicates a spot-and-fill pattern of spread.

RESUMEN

La invasión y expansión poblacional de la especie europea *Erucastrum gallicum* (Brassicaceae) en Norte América se rastrea desde la primera colección (1903) hasta 1992. La planta se ha encontrado en 29 estados de los Estados Unidos y en todas las provincias y un territorio del Canadá. El acrecentamiento del ámbito en Norte América, demostrado en cuatro mapas, indica un modelo de expansión poblacional de "spot-and-fill."

Although it is recognized that invasion of biological communities by alien species is important both economically and ecologically, few data exist on invasion patterns of plants in North America. When such patterns are known (e.g., Barbour and Rodman 1970; Forcella and Harvey 1988; Mack 1981; Stuckey 1979, 1980a, 1980b, 1985; Stuckey and Phillips 1970), the point(s) of original introduction can be determined and the route(s) of subsequent dispersal traced. This type of information is valuable for predicting possible outcomes of future invasions whether these are accidental or deliberate.

About 20% of the 5500 species of vascular plants in the flora of northeastern United States and adjacent Canada—the "Gray's Manual range" (Fernald 1950)—are aliens, and most of these are from Eurasia. This Eurasian element is positively associated with human disturbance and can comprise up to 73% (Baker 1986), or even more, of the species found in some biological communities. Understanding the invasion process requires an understanding of how plants interact with human activities.

In this paper we document the invasion and spread of *Erucastrum gallicum*

(Willd.) O.E. Schulz (dog mustard, French dog mustard) in North America. This species, a Eurasian import, appeared in the Gray's Manual range early in the 20th century. Dog mustard is a widespread species with narrow habitat requirements. Because it is limited to specific habitat types, it can be considered a "minor weed" (*sensu* Baker 1974) and may offer a special opportunity to assess how the activities of people can facilitate plant invasion.

IDENTIFICATION AND ECOLOGY OF *ERUCASTRUM GALLICUM*

Certainly no mustard in North America is easier to identify than *E. gallicum* (Fig. 1), with its bracteate proximal pedicels, which are unusual in the family (Masters 1875). This feature alone separates the species from most other mustards in its North American range. Nevertheless, we have seen specimens of the plant misidentified as *Arabidopsis thaliana*, *Brassica nigra*, *B. rapa*, *Diplotaxis eruroides*, *D. muralis*, *D. tenuifolia*, *Rorippa curvisiliqua*, *Sisymbrium auriculatum* (= *Coelophragmus auriculatus*), *S. incisum* (= *Descurainia incana* subsp. *incisa*), *S. irio*, *S. loeselii*, and *S. officinale*. Misidentifications of dog mustard persist into the 1990s even though *E. gallicum* is now included in many U.S. and Canadian floras.

Erucastrum gallicum is a summer annual, or rarely a winter annual (Klemow and Raynal 1983) or a biennial (Gleason and Cronquist 1963). The plants grow in sparsely vegetated habitats, most commonly along railroads and roadsides and in waste ground (see also Rollins 1981). They are characterized by high reproductive output and a persistent seed bank (Klemow and Raynal 1983). This species differs from many other weedy annuals in that only a small percentage of seeds in the seed bank germinates in any year. Such a life history trait apparently buffers the effects of year-to-year climatic variation and allows population persistence, but may also limit the potential of this species to become weedy (Klemow and Raynal 1983).

EARLY INVASION AND CURRENT DISTRIBUTION

The first published report of dog mustard (as *E. pollichii*) for North America is that of Robinson (1911). The voucher specimen, in the Gray Herbarium (GH), bears only scant data: "W. Finger, Milwaukee [Wisconsin], recd. 1905." Supplemental data, apparently received by Robinson from William Finger himself and included in Robinson's paper, indicate that the specimen was collected in 1903 "along the tracks of a suburban electric line, just beyond the city-limits of Milwaukee." The manner of introduction of the seed is unknown, but Milwaukee, although an inland city, has been a port of entry since the mid 1800s for ships from Europe and elsewhere (Mabee 1961).

That Robinson did not report dog mustard as "adventive" in North America until 1911 explains why the species was not included in the 1908 edition of *Gray's manual* (Robinson and Fernald 1908). Curiously, it was also not included in the 1913 edition of the Britton & Brown flora (Britton and Brown 1913).

Our herbarium search revealed three additional collections made in the first

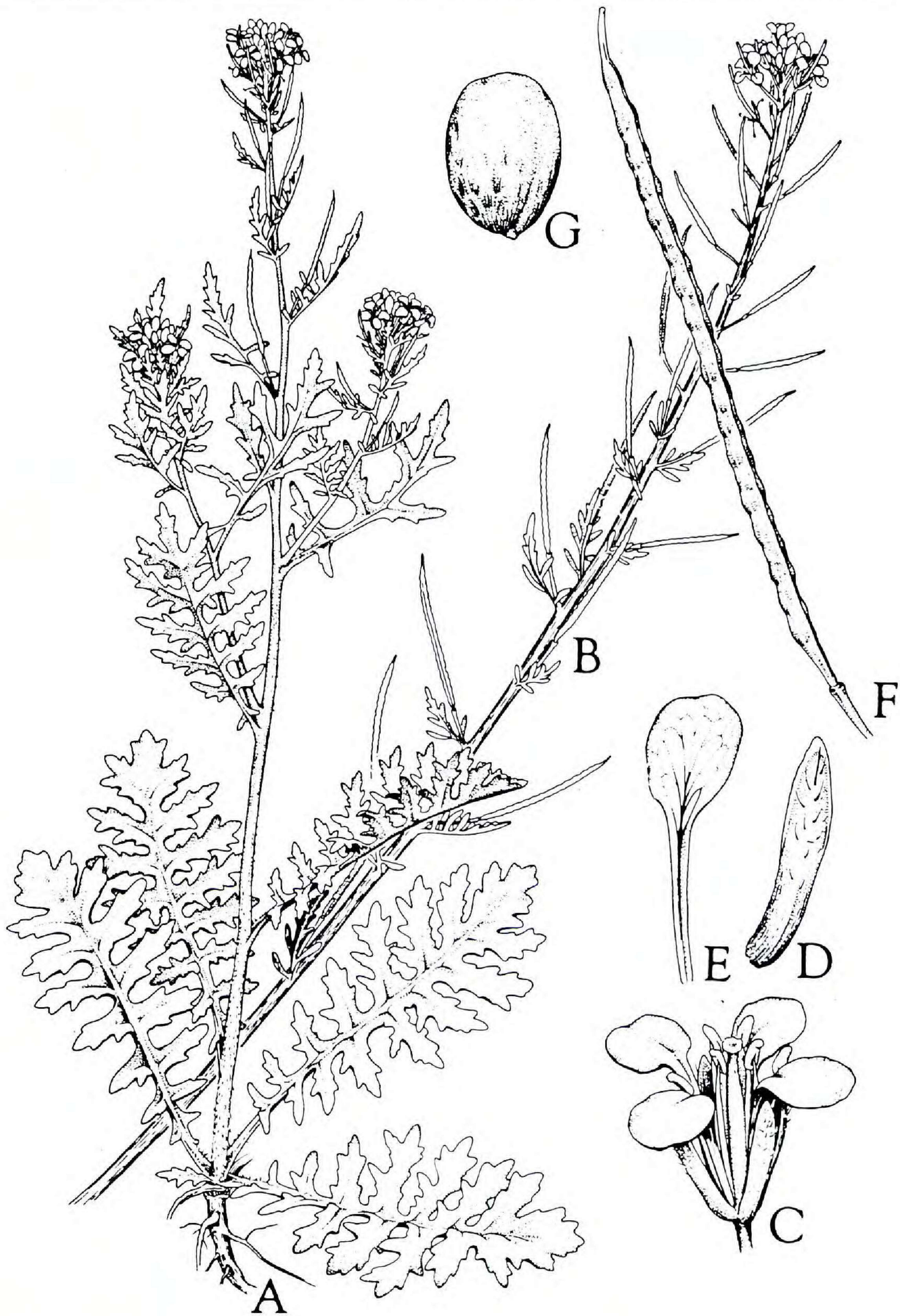


FIG. 1. *Erucastrum gallicum*, dog mustard. a. Habit, $\times 1/3$. b. Flowering and fruiting raceme, $\times 1/3$. c. Flower, $\times 5$. d. Sepal, $\times 10$. e. Petal, $\times 7.5$. f. Fruit, $\times 2.5$. g. Seed, $\times 12.5$. Illustration from Mohlenbrock (1980).

decade of the 20th century: one each from North Dakota, Ohio, and Wyoming in 1909. During that decade, then, *E. gallicum* was present in four widely spaced localities in the United States.

During the second decade, collections of dog mustard were made in seven additional states: Massachusetts, Minnesota, Missouri, Montana, New York, Vermont, and West Virginia. The species was not reported from Canada until the third decade, when it was recorded first in Manitoba, followed soon by Ontario, Prince Edward Island, and Quebec (Groh 1933, 1934, 1941). Groh (1933) maintained that *E. gallicum* was probably present in Canada at earlier dates but was not officially recorded because of problems with identification. Similarly, it was probably also present in the United States prior to 1903.

With continuing spread from the 1930s to the present, the species has now been collected in at least 29 states of the United States from coast to coast and in all provinces and one territory of Canada. The many collections span, in latitude, 36 degrees from the Northwest Territories (ca. 61° N) south to Florida (ca. 25° N) and, in altitude, from sea level to at least 2000 m in the western mountains.

We list here the political areas in which dog mustard has been found and the date of the earliest specimen we have seen from each area. Following the dash after some of the dates are references to literature (excluding floras) that we have noted as being applicable to *E. gallicum* in those political areas.

UNITED STATES (1903–Robinson 1911): **Alabama** (1970), **California** (1929), **Connecticut** (1951), **Florida** (1977–Popenoe and Ward 1978), **Idaho** (1930), **Illinois** (1940–Steyermark and Swink 1949), **Indiana** (1930–Standley 1932), **Iowa** (1935), **Kansas** (1945), **Kentucky** (1938–Carr and Cohn 1941), **Maine** (1925–Bean et al. 1961; Kidder 1926), **Massachusetts** (1910–Bean et al. 1961; Blake 1928; Knowlton and Deane 1916; Robinson 1911), **Michigan** (1922–Farwell 1924), **Minnesota** (1910–Butters and Abbe 1953; Lakela 1939), **Missouri** (1912–Mühlenbach 1979), **Montana** (1919–Blake 1953), **New Hampshire** (1942–Bean et al. 1961), **New York** (1910–Muenscher and Maguire 1931), **North Dakota** (1909), **Ohio** (1909–Easterly 1964), **Oregon** (1975), **Pennsylvania** (1927–Wahl 1945; Wilkens 1940), **South Dakota** (1941), **Texas** (1926), **Vermont** (1911–Blake 1914), **Washington** (1923), **West Virginia** (1919–Blake 1924; Corbett 1973), **Wisconsin** (1903–Patman and Iltis 1961; Robinson 1911), **Wyoming** (1909).

CANADA (1922–Frankton and Mulligan 1987; Groh 1933): **Alberta** (1922–Groh 1937), **British Columbia** (1939–Groh 1941), **Manitoba** (1922–Batho 1939; Groh 1933, 1934), **New Brunswick** (1937–Groh 1939), **Newfoundland** (1948), **Northwest Territories** (1974–Cody 1978), **Nova Scotia** (1936–Groh 1933, 1934 [Groh cited a 1932 specimen but this was returned to the collector and is apparently no longer extant]), **Ontario** (1924–Groh 1933, 1934 [date of earliest Ontario collection mistakenly cited as 1925]; Montgomery 1957; Rousseau 1971b); **Prince Edward Island** (1926–Groh 1933, 1934), **Quebec** (1927–Groh 1933, 1934; Rousseau 1968, 1971b), **Saskatchewan** (1932–Groh 1933, 1934).

In summer 1992 one of us (JWT) searched for dog mustard in *many* likely sites in what we have come to call the *Erucastrum* belt of North America, i.e., Minnesota, the Dakotas, Alberta, Saskatchewan, and Manitoba. No plants of it were found, not even in a Minneapolis railroad yard where, in 1980, JWT had

seen numerous individuals of it. The only collection JWT made of the species during 1992 was far from the center of distribution of the species in North America: in downtown St. John's, Newfoundland.

Erucastrum gallicum may be extinct in many of the areas where it was originally collected. Myers and Henry (1979) noted that a number of alien plants in Illinois were not present 24-130 years after their initial collection in the state. These authors hypothesized that many "railroad or highway migrants did not persist" because modern pure seed laws reduced the chances for new introductions and spread.

MAPPING INVASION PATTERNS

Studies of changes in ranges of plant species rely primarily on specimens preserved in herbaria and secondarily (because of possible errors in identification) on literature records. Previous research suggests that plant collections are indeed reliable indicators of weed distribution (Forcella 1985). To document the invasion and spread of dog mustard in North America, we borrowed specimens from 70 U.S. and Canadian herbaria (see Acknowledgments). From each of the 1070 herbarium sheets we examined, we recorded the herbarium of deposit, collector, date of collection, habitat, and pertinent morphological data. No literature records were used although we include references to those we could locate.

We show on four maps (Figs. 2 and 3) of North America (between about the 60th parallel and the United States/Mexican border) the spread of *E. gallicum* in four time periods, the first three of these being 2 decades each, the fourth being 3+ decades: map 1 (Fig. 2A), 1900-1919; map 2 (Fig. 2B), 1920-1939; map 3 (Fig. 3A), 1940-1959; and map 4 (Fig. 3B), 1960-1992. The first map was produced by affixing a piece of graph paper (each square representing ca. 25,600 km²) to a tracing box. Then our map of North America was positioned over the graph paper. Collection sites were located on the map and assigned to one of the underlying graph squares. If at least one collection fell within a particular graph square, a circle was placed centrally (relative to the graph square) on the map; one circle—and one only—was placed in each square, regardless of the number of localities that fell within that square. The remaining maps were produced in a similar way, the circles representing graph squares newly occupied for each time period, the dots representing graph squares occupied during the previous period(s). In a few instances, procrustean application of this method (*central* location of circles) resulted in a symbol being placed in a body of water (e.g., the circle in the Gulf of St. Lawrence near Prince Edward Island, representing a collection from that province) or in a state or province (or even a country) different from the actual locality of the collection being mapped. The circles and dots of the final map (Fig. 3B) represent the total North American range of *E. gallicum* as verified by us through 1992 from herbarium specimens.

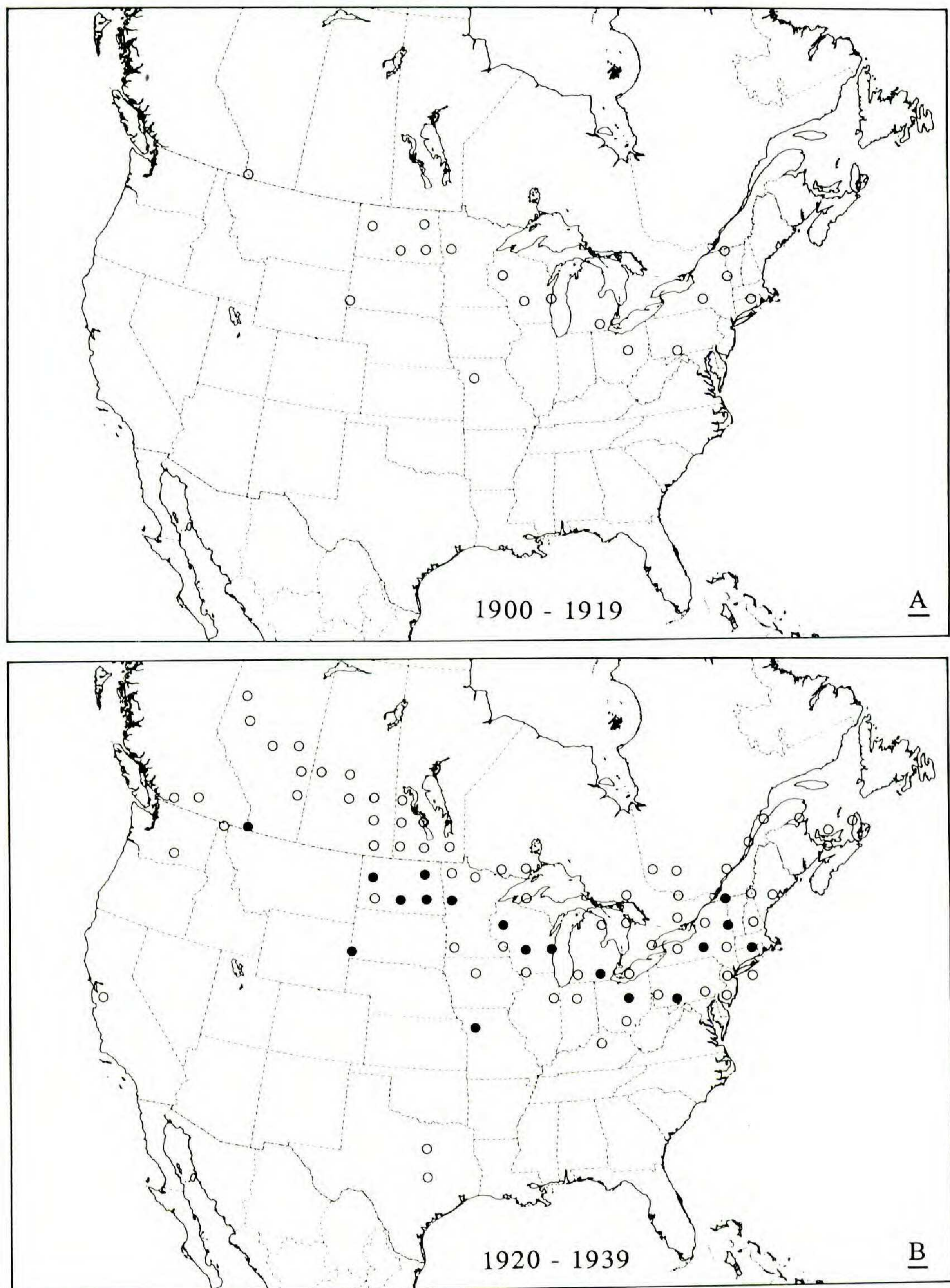


FIG. 2. Documented distribution of *Erucastrum gallicum* in North America, 1900–1939. Each circle represents the first occurrence of the species in a 25,600 km² area during the indicated time period; dots represent occurrences during previous time period(s). A. 1900–1919. B. 1920–1939.

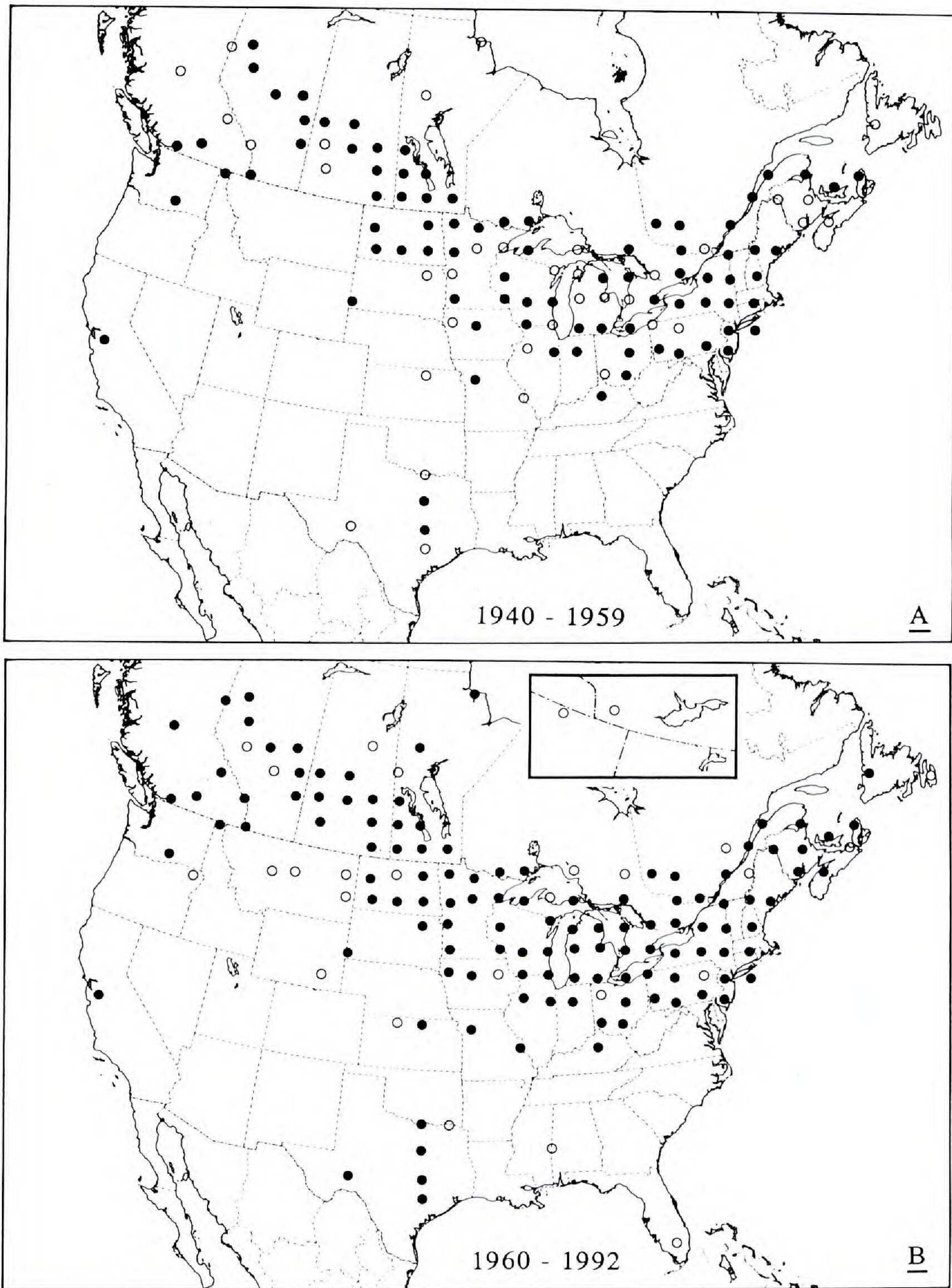


FIG. 3 Documented distribution of *Erucastrum gallicum* in North America, 1940–1992. Each circle represents the first occurrence of the species in a 25,600 km² area during the indicated time period; dots represent occurrences during previous time period(s). A. 1940–1959. B. 1960–1992. Inset shows northern British Columbia, northern Alberta, southwestern Mackenzie, and southeastern Yukon.

OBSERVATIONS ON HABITAT

In the sesquipedalian terminology so beloved by ecologists, dog mustard seems best described as an "epoecophyte" (Rousseau 1971b), defined by Rousseau (1971a) as a species established "seulement dans les endroits rudéraux et/ou les champs cultivés." Its most common habitat is railroads followed by roadsides, waste ground, and then various other open, sparsely vegetated sites (Fig. 4). Sometimes *E. gallicum* occurs as a weed in cultivated fields (Alex 1966; Groh 1933), but clearly this is not the most common habitat. After the crop is harvested, dog mustard plants may sometimes "fill a field with bloom in September" (Batho 1939).

The types of habitats where dog mustard most commonly occurs and long-term demographic data (Klemow and Raynal 1983) suggest that the plants do not require disturbance for establishment. Rather, they become established in denuded sites that are sparsely vegetated as a result of past disturbance, low fertility, and harsh microclimate. In the absence of repeated disturbance, *E. gallicum* may persist if competing vegetation is suppressed (Klemow and Raynal 1983), or it may be eliminated through competitive interactions (Milberg 1991). The most recent collections we examined did not suggest that *E. gallicum* is currently a major weed.

INVASION PATTERNS

Baker (1974) identified two patterns of spread by invaders. These are best described as "echelon" movement and "spot and fill" movement. In "echelon" movement, plants have a single point of introduction followed by movement across the landscape in wave- or step-like progression, e.g., *Filago arvensis* (Forcella and Harvey 1982). In "spot and fill" movement, several centers of introduction may be followed by a filling of the intervening open spaces. Clearly, *E. gallicum* is characterized by the "spot and fill" pattern. According to Baker (1974), the latter is the most common pattern of weed invasion in North America.

Some evidence suggests that regional movement of *E. gallicum* is associated with the transportation system. Most notable is the band of *E. gallicum* that penetrates Canada via a route through Manitoba, Saskatchewan, and Alberta and the line of *E. gallicum* through Texas. Both routes parallel railroads.

Railroads contribute suitable habitat and possibly a mechanism for dispersal. As noted by Mühlenbach (1979), frequent spraying with herbicides in railroad yards creates extensive open habitat that is colonized by a host of invasive species. Furthermore, the attachment of seeds to the surface of trains or the presence of seeds in the cargo of trains may facilitate long-distance dispersal. Seeds may also be spread through importation of forage (as on St. Pierre; Roger Etcheberry, pers. comm.) or grain (as in Britain; Carruthers 1865) for stock.

All of the first collections of *E. gallicum* in the United States presented on map

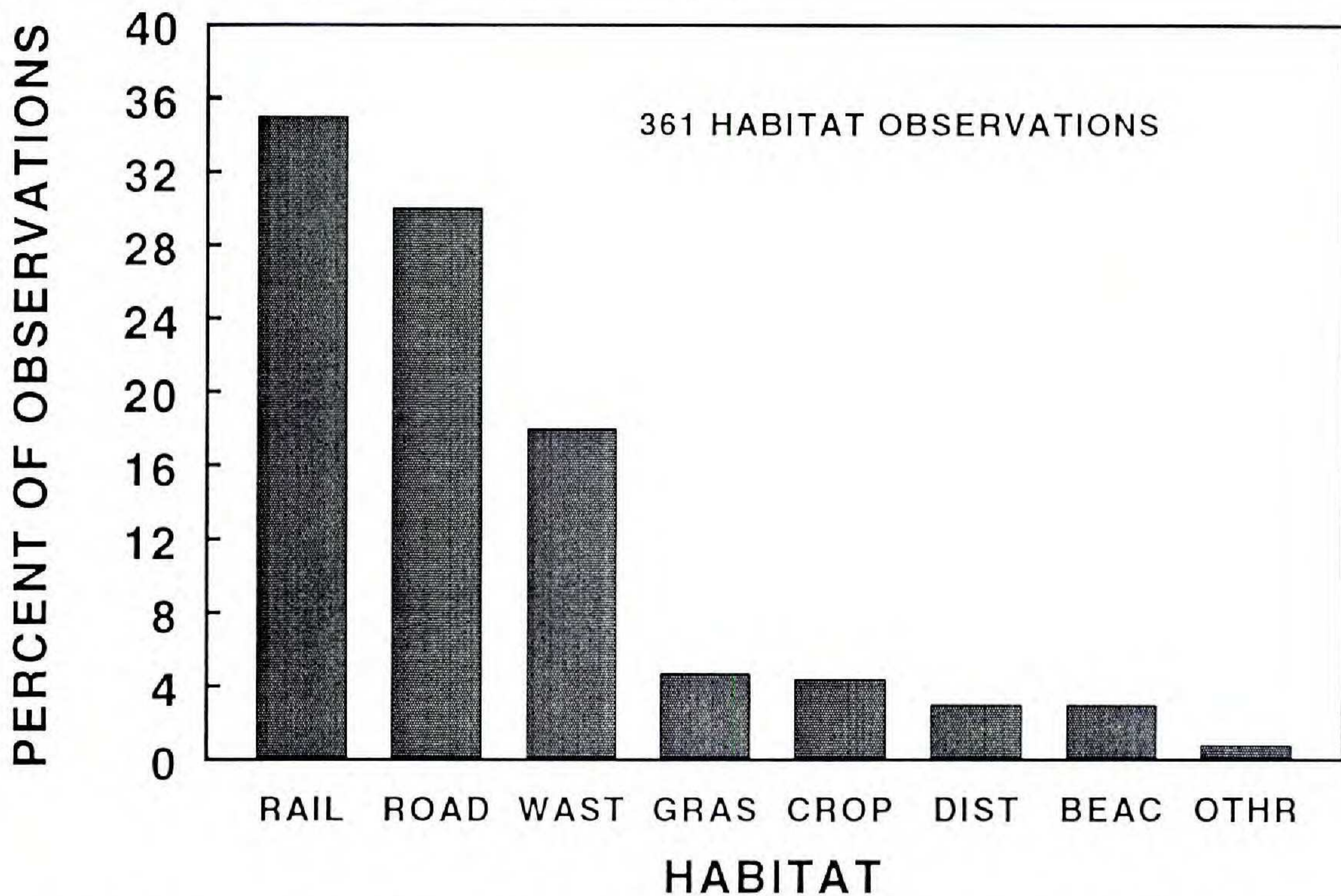


FIG. 4. Percentage distribution of habitats where *Erucastrum gallicum* has been collected, 1900-92. RAIL = railroad; ROAD = roadside; WAST = waste ground; GRAS = grassland; CROP = cropland; DIST = disturbed ground; BEAC = beach; OTHR = other habitats.

1 (Fig. 2A) were made along railroads; thus we assume that railroads facilitated the initial spread here. In Canada a similar trend is noted, with the exception that initial collections span a greater range of habitats and that cultivated fields are better represented. This suggests possible introduction through contamination of crop seed. Further evidence suggesting movement of *E. gallicum* in grain shipments is provided by collections near grain elevators and at grain shipping terminals, e.g., at Churchill, Manitoba.

Erucastrum gallicum may have reached its maximum rate of spread soon after invasion into North America; it may also be close to expressing its final distribution. From its initial establishment during 1900-1919, it reached its greatest rate of spread during 1920-1939 (3.4 graph squares/year). The rate was then slower during 1940-1959 (1.8 graph squares/year) and slower yet during 1960-1992 (0.8 graph squares/year). The lack of explosive invasion across large areas of North America indicates that *E. gallicum* is not likely to become a major problem weed (Forcella 1985).

ADDITIONAL NOTES ON DISTRIBUTION

Dog mustard was first collected on Saint-Pierre et Miquelon in 1982 near the Animal Quarantine in the town of St. Pierre (Roger Etcheberry, pers. comm.), possibly introduced via the forage imported from 1964 to 1976 for quarantined

animals (cattle to be sent to Canada). The voucher specimen (Abraham 347) sent to NFLD is apparently lost.

A California specimen of *E. gallicum* (Van LöbenSels [?] *s.n.*, CAS) collected on the campus of Stanford University in 1929 was the basis for the report by Abrams (1944) that dog mustard was "locally introduced in Santa Clara County, California." The species was *not* included in the California flora by Munz and Keck (1959) or in the account of alien plants of California by Robbins (1940), but it *does* appear in the revision of the Jepson California manual (Hickman 1993) on the basis of the Stanford collection (Susan M. Dalcamo, pers. comm.).

The Louisiana report of dog mustard (MacRoberts 1979, 1989) was based on misidentification of a species of *Brassica*.

TAXONOMY

Erucastrum is a genus of about 20 species endemic to western Eurasia (east to the Arabian Peninsula), Macaronesia, and much of Africa (Al-Shehbaz 1985; Rytz 1936). The genus has been considered to be a section of *Brassica* or of *Hirschfeldia*, but recent authors have maintained it as distinct and closely related to *Brassica* (Al-Shehbaz 1985).

The following description of *E. gallicum* is based on our study of ca. 1000 specimens, all of them from North America.

Erucastrum gallicum (Willd.) O.E. Schulz

Sisymbrium gallicum Willd.

Diploaxis bracteata Godr.

Erucastrum pollichii Schimp. & Spenn.

Hirschfeldia gallica (Willd.) Farwell

More extensive synonymy, mostly not applicable to North American literature, is given by Al-Shehbaz (1985) and by Schinz & Thellung (1921).

Annual (rarely winter annual or biennial), with taproot. Stem erect or ascending, unbranched or branched from the lower nodes, 0.9–6.5(8) dm tall, sparsely to densely pubescent with mostly retrorse, simple trichomes, especially below. Basal and lower leaves oblanceolate, 3–28 cm long and 0.8–11 cm wide, sometimes anthocyanous-tinged (especially below), sparsely pubescent, merely acute- or obtuse-toothed to usually deeply lobed, proximal lobes the smallest, terminal lobe often the largest, lobes mostly 3–10 on each side, 0.2–4.5 cm long, crenately or angularly dentate to lobed; cauline leaves similar, progressively reduced, the uppermost 1–2 cm long, passing gradually into floral bracts, the uppermost bracts usually progressively less deeply lobed, becoming as short as 2 mm long and 0.3 mm wide, entire, linear. Inflorescences terminal, conspicuously elongating in fruit, the proximal pedicels bracteate at base. Flowers in racemes; pedicels 2–16 mm long; sepals 2.5–4.5 mm long, erect to spreading, somewhat cucullate at tip; petals pale yellow or whitish, spatulate, 4–8 mm long; nectar

glands 4 (one subtending each of the two pairs of long stamens, one between the ovary and each of the two short stamens [Clemente Muñoz and Hernández 1978]); ovary cylindrical, stigma capitate; ovules numerous. Siliques usually upcurved, \pm linear, often somewhat torulose, body 1–4.5 cm long, 1–2(2.7) mm wide, 4-angled, beak 1.5–4 mm long, without seeds, septum 0.9–1.5 mm wide, valves 1-veined; seeds in 1 row in each locule, 1.1–1.5 mm long, 0.7–0.8 mm wide, reddish orange, alveolate (Murley 1951), cotyledons conduplicate. ($n = 15$ [Harberd 1972]; $2n = 30$ [Manton 1932; Mulligan 1957]). Flowering March through December (depending on locality), maturing fruit soon thereafter.

ETYMOLOGY

The common name “dog mustard” is a more or less literal translation of a German common name for this species, *Hundsrauke*, in which *rauke* refers to *Eruca sativa* Mill. (rocket-salad, garden rocket, rocket, roquette) and *Hunds* implies false or spurious (Marzell 1951)—all suggesting a resemblance to *Eruca sativa*. The generic name, *Erucastrum*, means much the same, false eruca, deriving from *Eruca* + the suffix *astrum*, indicating similarity. The specific epithet, *gallicum*, derives from the commonness of the species in western Europe (Marzell 1951).

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